Fully Coupled Atmosphere-Wave-Ocean Modeling of Tropical Cyclones and Impacts over the Western Pacific Ocean

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LONG-TERM GOALS

The long-term goal of this PI team is to understand the physical processes of the air-sea interaction and coupling of the atmosphere-ocean system in high-wind maritime regimes, with a particular emphasis on tropical cyclones. One of the most complex aspects in the air-sea coupling is the effect of surface waves at the air-sea interface that is not clearly defined in the high-wind conditions. We aim to determine the physical processes that must be represented in coupled atmosphere-wave-ocean models in order to simulate and predict the coupled atmosphere-ocean system under extreme wind conditions.

OBJECTIVES

The goal of this study is to better understand and observe tropical cyclones and their impact on the ocean over the western North Pacific and to improve prediction of tropical cyclone formation and development in the next generation research and operational coupled atmosphere-ocean prediction systems. The main objectives of this research are:

- To better understand and predict the tropical cyclones (TC) formation, structure, intensification/decay, and interactions with the ocean over the Western North Pacific and adjacent marginal seas

- To understand the formation, structure, and recovery of the TC-induced cold wake in the upper ocean and its impact on the immediate TC intensification/decay as well as subsequent TC formations

- To implement the CBLAST wind-wave coupling and air-sea flux parameterizations in fully coupled atmosphere-wave-ocean modeling systems for both research and operations in coastal and open oceans

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- To examine the effects of the surface waves on the OML dynamics and TC impact on the ocean in a fully coupled atmosphere-wave-ocean modeling system, and

- To evaluate and further improve the coupled modeling systems using both satellite data (including SAR observed waves and winds, scatterometer winds, SST/upper ocean temperature, and cloud/precipitation) and the in situ observations from the planned ONR field campaigns in the Western Pacific as well as measurements from the laboratory (e.g., wave tank at UM).

APPROACH

This proposed research builds on a number of major advancements from the prior ONR and NSF supported projects (e.g., CBLAST-Hurricane and RAINEX, Chen et al. 2007, Houze et al. 2006, 2007) and the expertise of the PI team on fully coupled atmosphere-wave-ocean modeling in TCs expertise on satellite data analysis of tropical convective systems over the western Pacific as well as on the ocean surface waves. The CBLAST wind-wave coupling that calculates wind-induced stress by explicit integration of surface wave spectra (Chen et al. 2007; 2009a, 2009b). In addition, the corresponding heat and moisture fluxes are also improved because of the indirect effect of the roughness length on the exchange coefficients. The new coupling parameterizations have been shown to improve the hurricane intensity forecast that is one of the most difficult problems in hurricane prediction today. We will first implement and test new coupling parameterizations in the existing modeling systems for applications in typhoons over the W Pac. We will use at least two different models for each components of the coupled system. This approach will produce flexible and portable, coupling parameterizations that can be implemented into the next generation coupled atmosphere-ocean prediction systems planned for the future, e.g., COAMPS and WRF, HYCOM and NCOM, and WAVEWATCH III.

An interesting, but unresolved question in our understanding of the impact of tropical cyclone on the upper ocean dynamics as well as the oceanic feedback to the storm structure and intensity is the OML parameterizations currently in the ocean circulation models. The development and evaluation of the mixing parameterizations are mostly done using either monthly mean or relatively low-resolution global wind analysis fields. There is a very large sensitivity and various mixed layer parameterizations to high winds in tropical cyclones. Zhao and Chen (2006) have shown the uncertainty of using different mixing parameterizations in hurricane conditions, especially in a two-hurricane tandem case in 2002. The physical and dynamical processes in OML can affect the generation and recovery of TC-included cold wake, which is one of the main foci of this research.

In this study, we will first define a set of parameters to characterize the typhoons and their impact on the ocean in the Western Pacific: radius of max wind (RMW) and radius of outer wind using a combined the Best Track data issued by JTWC and JMA, satellite IR and satterometer data, rainband pattern using TRMM TMI and PR data, environmental moisture using perceptible water vapor (PWV) data, and vertical shear using the

Statistical Typhoon Intensity Prediction Scheme (STIPS, Knaff et al. 2005, Chen et al. 2006), strength and recovering time of the cold wakes in the upper ocean and surface waves using SST and SAR data. We then compare these parameters to that of the Atlantic hurricanes. We will proceed to conduct coupled atmosphere-wave-ocean simulations over the Western Pacific and compare with the previous results based on CBLAST-Hurricane modeling and observations (Chen et al. 2007, Black et al. 2007).

A multi-model system will be set up for real-time forecasts in support of the ITOP field program. Observations from the satellite SAR and scatterometers will be added to the data base as ITOP continues over the next a few years. In situ measurements of the sea state, lower surface layer temperature, humidity, and wind data from the buoys will provide a good estimate of surface momentum and heat fluxes. In addition, potential shipborne and airborne drifters and floats data would provide the needed upper ocean observations. Collectively these data sets will provide much need evaluation and validation for the continued development and improvement of the fully coupled atmosphere-wave-ocean model for air-sea research and operational applications. A multi-year data and model intercomparison in typhoons over the western North Pacific will not only be valuable for that region, but also improve our understanding of the complex air-sea interactions in tropical cyclones in general for years to come.

WORK COMPLETED

We have completed the following coupled model development, simulations, and real-time forecasts of typhoons over the West Pacific:

- Configure and test of the University of Miami Coupled Atmosphere-Wave-Ocean Model (UMCM) over the West Pacific
- Fully coupled model simulations of Typhoon Jangmi (2008) and comparison with both satellite and airborne observations during TCS-08
- Conduct real-time coupled model forecasts of Typhoons Choiwan, Melor, Parma, and Lupit (2009) during the "dry run" experiments in preparation for the ITOP field campaign
- Investigate the characteristics of multi-typhoon induced-ocean circulation by including Typhoons Sinlaku and Hagbit (2008) coupled model simulations in collaboration with Drs. I.I. Lin and C.C. Wu's research group at National Taiwan University

The finished analyses are available in real-time at: http://orca.rsmas.miami.edu/ITOP/.
In addition, more detailed analysis for each of the TCS-08 typhoon cases are available to privide a context for the 2008 season as well as a comparison for other typhoon seasons for ITOP in 2009-2010.

RESULTS

The scientific findings of this study are summarized in Lee and Chen (2009) and Kerns and Chen (2009) and will be followed in two other up coming manuscripts by Chen et al. The most significant results of this study to date can be summarized as the following.

1) A multi-model high-resolution coupled modeling system has been configured and tested in real-time typhoon forecasts over the North West Pacific in 2009 at RSMAS/University of Miami. An mini-ensemble of high-resolution coupled and uncoupled models were run with various global model forecast fields, including GFS, NOGAPS, and CMC, as initial and lateral boundary conditions. The high-resolution atmospheric models are configured as multi-nested grids with 12, 4, and 1.3km resolutions, respectively. The ocean model used in coupled UMCM and CWRF are 3DPWP, which is initialized with the satellite SST from TRMM TMI and AMSR-E data and HYCOM 3D temperature fields. The 5-day forecasts from the high-resolution models are a major improvement to typhoon intensity forecasts, which have used and evaluated during the Dry Run experiment for ITOP from September-October 2009. Figure 1 shows an example of the multi-model high-resolution modeling system real-time forecasts of Typhoon Lupit from October 15-18, 2009. The models are initialized at 0000 UTC each day and produce 5-day forecasts for the period time continuously during the dry run. Although the track forecasts are similar to the global models, the high-resolution models predicted the rapid intensification in Lupit, whereas the global models showed no skill in intensity forecasts.
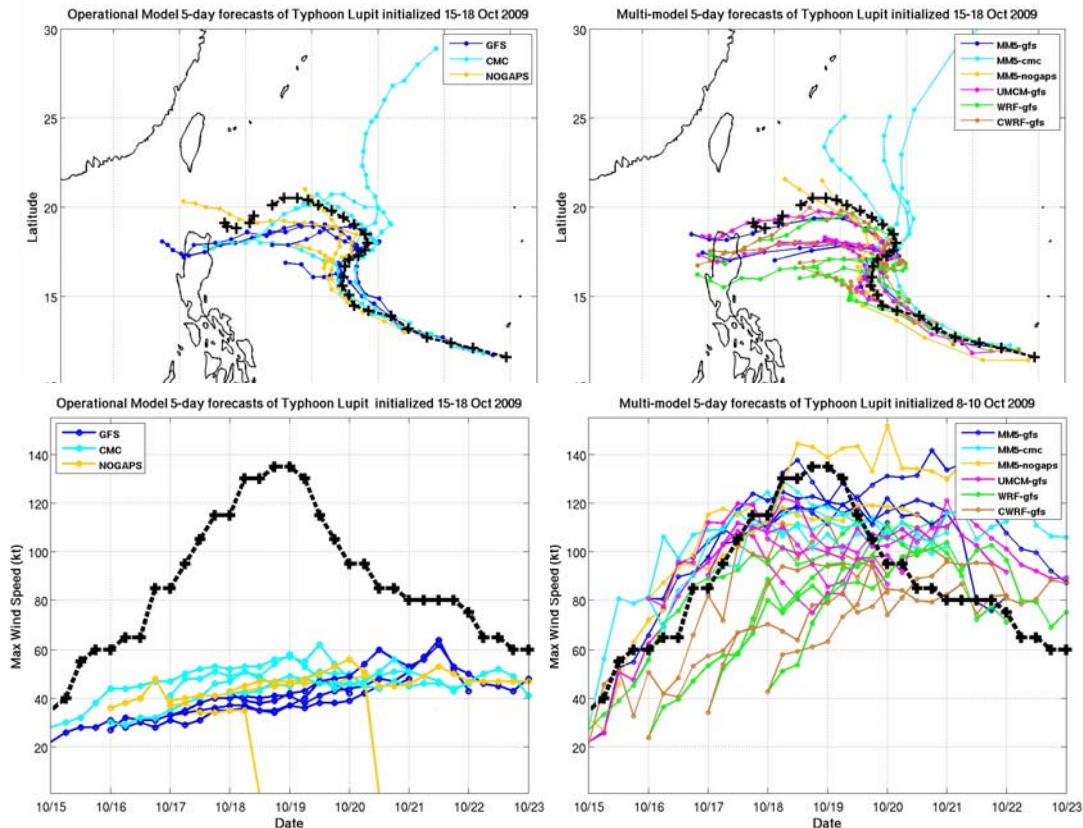

Figure 1 Multi-model high-resolution model real-time forecasts of Typhoon Lupit from October 15-18, 2009 (right panels) compared to the global model forecasts (left panels). The track forecasts are the top panels and intensity (max surface wind speed in kts) lower panels. The models are initialized at 0000 UTC each day. The JTWC best estimated track/intensity data are in black lines.

2) The coupled models captured a variety of typhoon-induced cold wakes in Typhoons Jangmi (2008), Melor (2009) and Lupit (2009), with the maximum cooling ranging from 2-7 ^{o}C as observed by the satellite retrieved SST from the TRMM and AMSR-E data. Figure 2 shows examples of the coupled models (UMCM and CWRF) forecasts of Typhoon Lupit-induced cold wake from October 15-19 and October 18-23, 2009.

3) It is found that the most distinct characteristics of Typhoon Lupit is the slow translation speed from October 17-19 when the maximum ocean response were predicted by the coupled models and observed by satellite retrieved SST from TRMM TMI and AMSR-E data (Fig. 2). The SST anomaly showed a 5-7 ^{o}C cooling. The typhoon structure and intensity were well-forecasted in the high-resolution coupled models, which are critical for capture the ocean response. The strong cooling has contributed in part to the weakening of Lupit after October 19. These features were not resolved in operational NCOM or HYCOM, most likely due to the lack of accurate atmospheric forcing in those models.
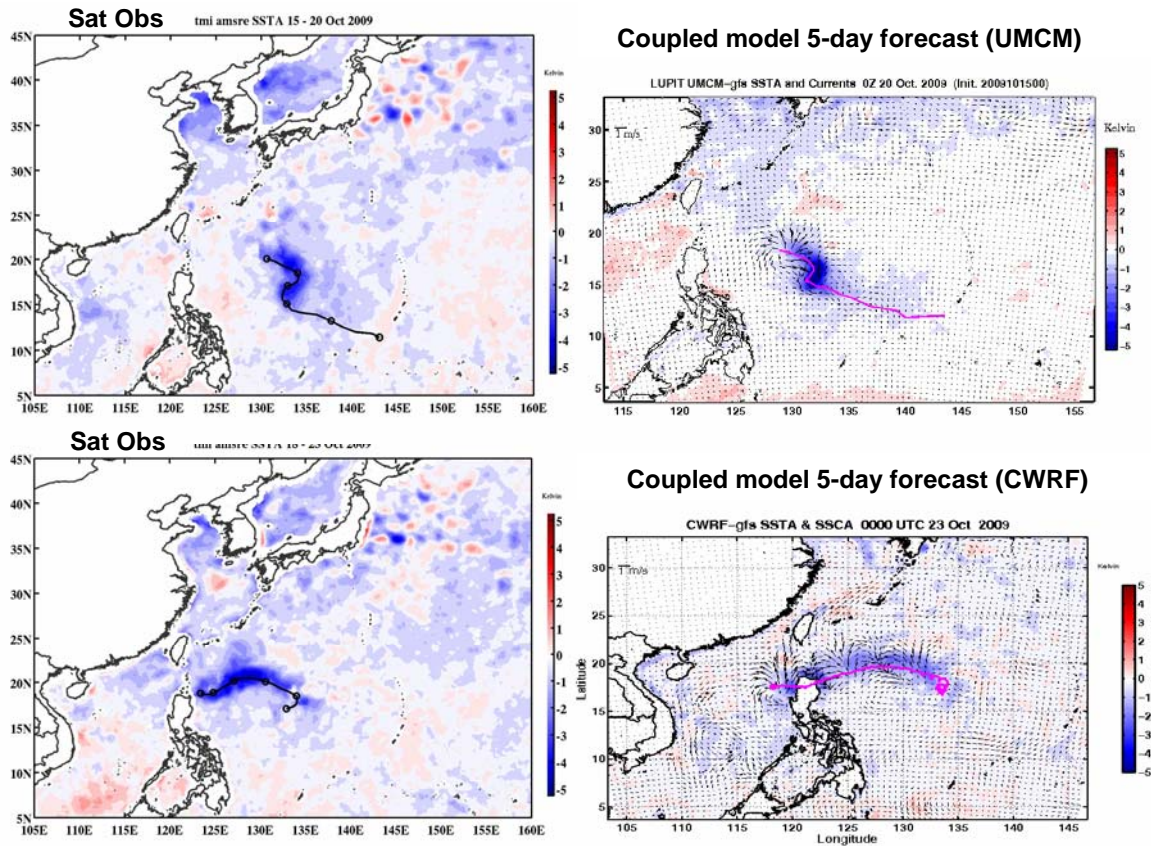

Figure 2 Coupled models, UCMC and CWRF, 5-day forecasts of Typhoon Lupit-induced cold wake shown as sea surface temperature anomaly (SSTA, in color) and surface curents (right panels, vectors) from October 15-19 (top) and October 18-23 (bottom). The models are run in multi-nested grids with the highest resolution of 1.3 km in the inner most model domain. The satellited observed SSTA from TRMM TMI and AMSR-E data are shown in the left panels. Model forecasted (magenta) and observed (black) tracks are overlaid.

IMPACT/APPLICATIONS

The results from this study will have a significant impact on prediction of typhoon intensifucation/decay processes, especially typhoon interactions with the upper ocean over the North Weat Pacific. First, the coupling between the cloud cluster tracking and favorability indexes developed in this study can potentially lead to improvement in increase of lead time for TC genesis forecasting, which will be valuable for operational applications. Second, the characteristics of cloud clusters can be used as a new way of evaluate and verrfy numerical model simulations and forecasts of TC formation.

RELATED PROJECTS

Drs. Chen and Kerns have been working with the Tropical Cyclone Structure in 2008 (TCS-08) using the method developed in this study to predict the early development of TCs over the West Pacific in 2009. The real-time cloud cluster analysis developed under TCS-08 will provide guidance and climatological context for TCs in West Pacific and be used for planning of ITOP missions during the field program in 2010.

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